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Date: 21st December 2025

AI-Driven Sorting Algorithm Optimizer

Report

CST207 Design and Analysis of Algorithms Group Project

Academic Session: 2025/09

Oral Presentation Video Link

https://drive.google.com/drive/folders/1YNGKs7LQVs_FJW2VaJKDxGBAhHr5GaCm

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Group Contribution Table

Student ID	Name	Specific Contribution Description
DSC2409006	Cui Zeyu	Implement Result Visualization GUI with Qt, Write Report and Edit Oral Presentation Video
DSC2409010	Fan Li	Implement AI Model with kNN and Decision Tree
DSC2409012	He Bingguang	Implement AI Model with kNN and Decision Tree
DSC2409042	Yu Fangrui	Implement Dataset Generation for All Types and Testing
DSC2409043	Yu Mingquan	Implement Sorting Algorithms and Measure Performance

1 Introduction

In modern software engineering, sorting is a fundamental operation whose performance critically depends on the characteristics of the dataset—such as size, order (sortedness), and element uniqueness. While standard libraries often use a one-size-fits-all approach (typically Quick Sort or Insertion Sort), no single algorithm is optimal for every scenario.

The goal of this project is to design and implement an **AI-Driven Sorting Algorithm Optimizer**. This system acts as an intelligent library that analyzes the input dataset's features and automatically selects the most efficient sorting algorithm. By integrating Artificial Intelligence (Decision Tree model) with traditional algorithmic analysis, we demonstrate how heuristics can optimize computational resource usage.

2 System Overview

In Figure 1, we illustrate the overall architecture of the system:

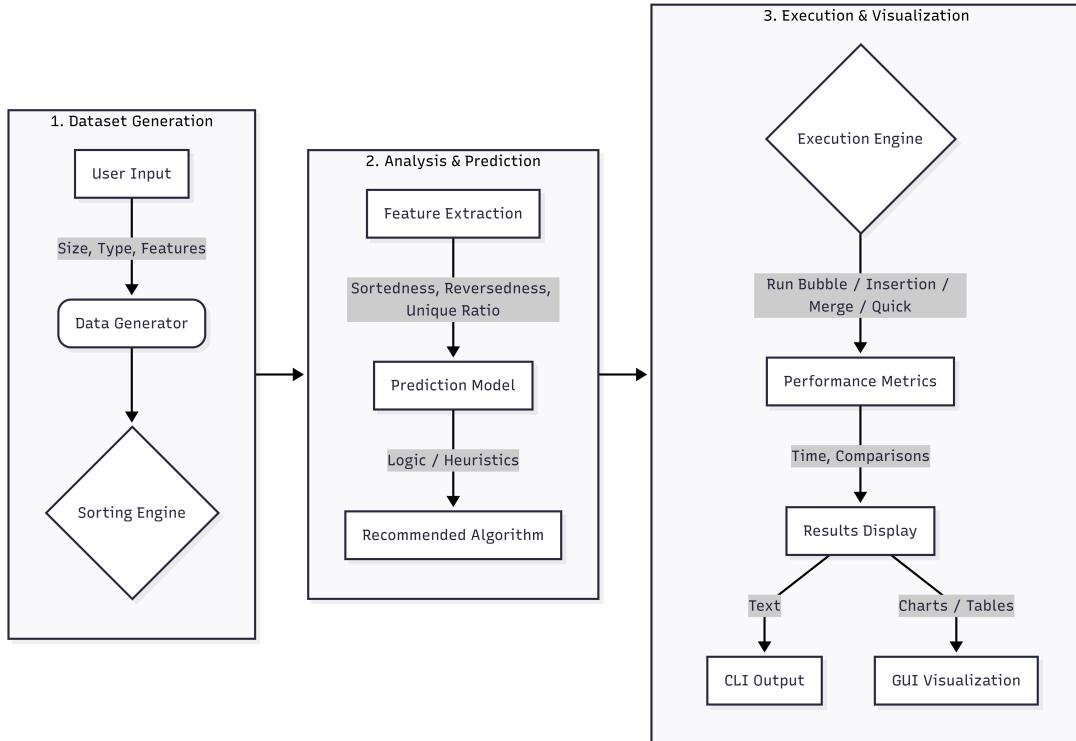


Figure 1: System Architecture Overview

The system consists of three main components:

1. **Dataset Generation:** Generate five dataset types (random, nearly sorted, reversed, few-unique, large random) with configurable size and distribution for comprehensive benchmarking. The generated datasets will be sorted by algorithms.
2. **Analysis and AI Module Prediction:** Extract features (size, sortedness, reversedness, unique ratio) and use decision-tree models to recommend the most suitable sorting algorithm. The decision tree in the AI module is constructed based on empirical observations and theoretical analysis of algorithm performance.
3. **Execution and Visualization:** Execute chosen algorithms, measure runtime and comparisons, and present results via CLI text and GUI tables. AI predictions are compared against actual performance to validate accuracy and shown visually.

3 Algorithm Design

Note that: To make the layout neater, all code in the main body of the report is un-commented. The relevant explanations will be provided in the text. Additionally, well-commented code will be added in full to the appendix.

3.1 Dataset Generation

To robustly test the algorithms, we implemented a generator capable of creating five distinct types of datasets, as required by the project specifications:

1. **Random Dataset:** Elements are generated using a random number generator with values in range $[1, \text{size} \times 10]$.

```
1 static vector<int> generateRandomDataset(int size) {
2     vector<int> arr(size);
3     srand(time(nullptr));
4     for (int i = 0; i < size; i++) {
5         arr[i] = 1 + rand() % (size * 10);
6     }
7     return arr;
8 }
```

2. **Nearly Sorted Dataset:** A sorted array is created, and then approximately 10% of the elements are randomly swapped to simulate slightly disordered data.

```
1 static vector<int> generateNearlySorted(int size) {
2     vector<int> arr(size);
3     for (int i = 0; i < size; i++) arr[i] = i + 1;
4
5     int swaps = size / 10;
6     srand(time(nullptr));
7     for (int i = 0; i < swaps; i++) {
8         int idx1 = rand() % size;
9         int idx2 = rand() % size;
10        swap(arr[idx1], arr[idx2]);
11    }
12    return arr;
13 }
```

3. **Reversed Dataset:** Elements in the dataset are strictly arranged in descending order ($N, N - 1, \dots, 1$).

```

1 static vector<int> generateReversed(int size) {
2     vector<int> arr(size);
3     for (int i = 0; i < size; i++) {
4         arr[i] = size - i;
5     }
6     return arr;
7 }
```

4. **Few Unique Dataset:** The dataset contains many duplicate values, generated from a small pool of unique integers. First, a pool of `uniqueCount` random values is created, then the dataset is filled by randomly selecting from this pool.

```

1 static vector<int> generateFewUnique(int size, int uniqueCount) {
2     vector<int> uniqueValues;
3     srand(time(nullptr));
4     for (int i = 0; i < uniqueCount; i++) {
5         uniqueValues.push_back(rand() % 100 + 1);
6     }
7
8     vector<int> arr(size);
9     for (int i = 0; i < size; i++) {
10        arr[i] = uniqueValues[rand() % uniqueCount];
11    }
12    return arr;
13 }
```

5. **Large Random Dataset:** A stress-test dataset with size $N \geq 10,000$ to evaluate asymptotic performance. Uses the same `generateRandomDataset()` method but enforces a minimum size constraint of 10,000 elements in the main program.

3.2 Sorting Algorithms

We implemented four classical sorting algorithms:

- **Bubble Sort ($O(N^2)$):** Included for educational comparison; effective only on very small or nearly sorted data. Features early termination optimization: if no swaps occur in a pass, the array is already sorted.

```

1 static void bubbleSort(vector<int>& arr, long long& comparisons) {
2     int n = arr.size();
3     for (int i = 0; i < n - 1; i++) {
4         bool swapped = false;
5         for (int j = 0; j < n - i - 1; j++) {
6             comparisons++;
7             if (arr[j] > arr[j + 1]) {
8                 swap(arr[j], arr[j + 1]);
9                 swapped = true;
10            }
11        }
12        if (!swapped) break;
13    }
14 }
```

- **Insertion Sort ($O(N^2)$):** Highly efficient for small N or nearly sorted data due to low constant factors. Each element is inserted into its correct position in the sorted prefix. For nearly sorted data, the inner while loop terminates quickly, achieving near $O(N)$ performance.

```

1 static void insertionSort(vector<int>& arr, long long& comparisons) {
2     int n = arr.size();
3     for (int i = 1; i < n; i++) {
4         int key = arr[i];
5         int j = i - 1;
6         while (j >= 0) {
7             comparisons++;
8             if (arr[j] <= key) break;
9             arr[j + 1] = arr[j];
10            j--;
11        }
12        arr[j + 1] = key;
13    }
14 }
```

- **Merge Sort ($O(N \log N)$):** A stable, divide-and-conquer algorithm that guarantees performance but requires $O(N)$ auxiliary space. The algorithm recursively divides the array, then merges sorted sub-arrays.

```

1 static void mergeSort(vector<int>& arr, int l, int r, long long&
2     comparisons) {
3     if (l >= r) return;
4     int m = l + (r - l) / 2;
5     mergeSort(arr, l, m, comparisons);
6     mergeSort(arr, m + 1, r, comparisons);
7     merge(arr, l, m, r, comparisons);
8 }
9 static void merge(vector<int>& arr, int l, int m, int r, long long&
10    comparisons) {
11     int n1 = m - l + 1;
12     int n2 = r - m;
13     vector<int> left(n1), right(n2);
14
15     for (int i = 0; i < n1; i++) left[i] = arr[l + i];
16     for (int j = 0; j < n2; j++) right[j] = arr[m + 1 + j];
17
18     int i = 0, j = 0, k = l;
19     while (i < n1 && j < n2) {
20         comparisons++;
21         if (left[i] <= right[j]) {
22             arr[k++] = left[i++];
23         } else {
24             arr[k++] = right[j++];
25         }
26     }
27     while (i < n1) arr[k++] = left[i++];
28     while (j < n2) arr[k++] = right[j++];
```

- **Quick Sort ($O(N \log N)$): Optimization:** To prevent the worst-case $O(N^2)$ time complexity on *Reversed Datasets*, we implemented a **Randomized Pivot** strategy.

The pivot is selected randomly, ensuring $O(N \log N)$ performance on average for any input distribution.

```

1 static void quickSort(vector<int>& arr, int low, int high, long long&
2   comparisons) {
3   if (low < high) {
4     int pi = partition(arr, low, high, comparisons);
5     quickSort(arr, low, pi - 1, comparisons);
6     quickSort(arr, pi + 1, high, comparisons);
7   }
8
9 static int partition(vector<int>& arr, int low, int high, long long&
10  comparisons) {
11   int randomIndex = low + rand() % (high - low + 1);
12   swap(arr[randomIndex], arr[high]);
13
14   int pivot = arr[high];
15   int i = low - 1;
16   for (int j = low; j < high; j++) {
17     comparisons++;
18     if (arr[j] < pivot) {
19       i++;
20       swap(arr[i], arr[j]);
21     }
22   }
23   swap(arr[i + 1], arr[high]);
24   return i + 1;
25 }
```

3.3 AI Module: Decision Tree Approach

We implemented a Decision Tree to predict the best algorithm. The AI module extracts four key features from the dataset: *Size*, *Sortedness* (ratio of ascending pairs), *Reversedness* (ratio of descending pairs), and *Unique Ratio*. The feature extraction is implemented by analyzing consecutive pairs and using `unordered_set` to count unique elements:

```

1 static DatasetFeatures analyzeDataset(const vector<int>& data) {
2   DatasetFeatures features;
3   features.size = data.size();
4   features.isLargeDataset = (features.size > 1000);
5
6   long long ascendingPairs = 0, descendingPairs = 0;
7   for (int i = 0; i < features.size - 1; i++) {
8     if (data[i] <= data[i+1]) ascendingPairs++;
9     if (data[i] >= data[i+1]) descendingPairs++;
10  }
11
12  features.sortedness = (double)ascendingPairs / (features.size - 1);
13  features.reversedness = (double)descendingPairs / (features.size - 1);
14
15  unordered_set<int> uniqueElements(data.begin(), data.end());
16  features.uniqueCount = uniqueElements.size();
17  features.uniqueRatio = (double)uniqueElements.size() / features.size;
18
19  return features;
20 }
```

The decision logic is as follows:

1. **Rule 1 (Small Dataset):** If $Size \leq 50$, predict **Insertion Sort**. The overhead of recursion in Merge/Quick Sort outweighs the simple logic of Insertion Sort for small N .
2. **Rule 2 (Large Dataset):** If $Size > 1000$:
 - If $UniqueRatio < 0.40$, predict **Merge Sort**. Merge Sort maintains $O(N \log N)$ stability with heavy duplicates, while Quick Sort may degrade due to unbalanced partitions.
 - Otherwise, predict **Quick Sort**. Quick Sort has the smallest constant factors and better cache performance for large datasets with good uniqueness.
3. **Rule 3 (Nearly Sorted):** If $Size \in (50, 1000]$ and $Sortedness \geq 0.80$, predict **Insertion Sort**. Insertion Sort degrades to $O(N + D)$ where D is inversions, achieving near-linear performance on nearly sorted data.
4. **Rule 4 (Reversed Order):** If $Size \in (50, 1000]$ and $Reversedness \geq 0.90$, predict **Merge Sort**. Merge Sort guarantees $O(N \log N)$ worst-case performance and is unaffected by initial element order.
5. **Rule 5 (Few Unique, Medium):** If $Size \in (50, 1000]$ and $UniqueRatio < 0.40$, predict **Merge Sort**. Same reasoning as Rule 2—duplicates favor Merge Sort's stability.
6. **Rule 6 (Default):** For all other cases, predict **Quick Sort**. Quick Sort is the best general-purpose algorithm with average $O(N \log N)$, smallest constant factors, and randomized pivot to avoid worst-case scenarios.

The complete decision tree is illustrated in Figure 2:

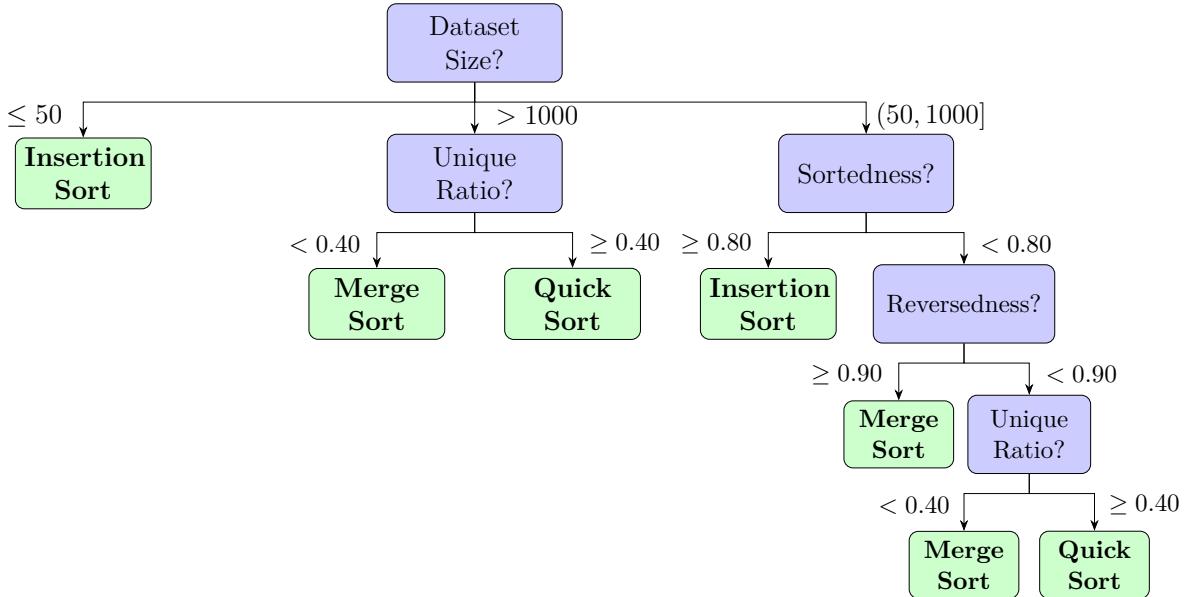


Figure 2: Decision Tree for Algorithm Selection

This decision tree effectively captures the heuristics derived from algorithmic analysis and experimental observations.

The decision tree logic for algorithm prediction is implemented as follows:

```
1 static AlgoType predictBestAlgorithm(const DatasetFeatures& features) {
2     if (features.size <= 50) {
3         return INSERTION_SORT;
4     }
5
6     if (features.isLargeDataset) {
7         if (features.uniqueRatio < 0.40) {
8             return MERGE_SORT;
9         }
10    return QUICK_SORT;
11 }
12
13 if (features.sortedness >= 0.80) {
14     return INSERTION_SORT;
15 }
16
17 if (features.reversedness >= 0.90) {
18     return MERGE_SORT;
19 }
20
21 if (features.uniqueRatio < 0.40) {
22     return MERGE_SORT;
23 }
24
25 return QUICK_SORT;
26 }
```

4 Implementation Details

4.1 Performance Measurement

The system measures two metrics for every run:

- **Comparisons:** A long long counter passed by reference increments on every element comparison.
- **Execution Time:** Measured using `std::chrono::high_resolution_clock` in milliseconds.

The `runSort` method encapsulates both measurement processes. It records the start time before calling the sorting algorithm, passes the `comparisons` counter by reference to be incremented during execution, and then calculates the elapsed time:

```
1 static SortMetrics runSort(AlgoType type, vector<int> data) {
2     SortMetrics metrics;
3     metrics.algoName = getAlgoName(type);
4     metrics.comparisons = 0;
5
6     auto start = chrono::high_resolution_clock::now();
7
8     switch (type) {
9         case BUBBLE_SORT: bubbleSort(data, metrics.comparisons); break;
10        case INSERTION_SORT: insertionSort(data, metrics.comparisons);
11    break;
```

```

11     case MERGE_SORT: mergeSort(data, 0, data.size() - 1, metrics.
12         comparisons); break;
13     case QUICK_SORT: quickSort(data, 0, data.size() - 1, metrics.
14         comparisons); break;
15     }
16
17     auto end = chrono::high_resolution_clock::now();
18     chrono::duration<double, milli> duration = end - start;
19     metrics.executionTimeMs = duration.count();
20
21     return metrics;
22 }
```

4.2 Safety and Optimization

To prevent system unresponsiveness, the implementation includes a safety check: if the dataset size exceeds 1,000 elements, $O(N^2)$ algorithms (Bubble and Insertion Sort) are automatically skipped. This ensures that “Large Random Datasets” (e.g., $N = 100,000$) only benchmark efficient $O(N \log N)$ algorithms.

When an algorithm is skipped, the `comparisons` and `executionTimeMs` are set to -1 as a marker, and the result table displays “(Skipped)” instead of numerical values. In the main execution loop, before running each algorithm, the system checks whether the algorithm’s complexity and dataset size combination would cause excessive delays. The safety threshold is set at 1,000 elements:

```

1 vector<AlgoType> algosToRun = {BUBBLE_SORT, INSERTION_SORT, MERGE_SORT,
2     QUICK_SORT};
3 vector<SortMetrics> results;
4
5 for (AlgoType algo : algosToRun) {
6     if (features.isLargeDataset && (algo == BUBBLE_SORT || algo ==
7         INSERTION_SORT)) {
8         SortMetrics skipped;
9         skipped.algoName = SortingEngine::getAlgoName(algo);
10        skipped.comparisons = -1;
11        skipped.executionTimeMs = -1;
12        results.push_back(skipped);
13        continue;
14    }
15    results.push_back(SortingEngine::runSort(algo, features.data));
16 }
```

4.3 Multiple Versions of Optimizer

The project includes both a Command Line Interface (CLI) and a Graphical User Interface (GUI) using Qt. The CLI allows users to specify dataset type and size, while the GUI provides an interactive experience with buttons, input fields, and result tables.

Note that: For full well-commented code, please refer to the Appendix 1 and Appendix 2. The following shows the main code without comments.

CLI Version: The command-line version provides a menu-driven interface for quick testing. Users select a dataset type (1-5), specify size, and the system displays formatted results in the terminal:

```

1 int main() {
2     while (true) {
3         displayMenu();
4
5         int choice;
6         cout << "Enter your choice: ";
7         cin >> choice;
8
9         if (choice == 0) {
10             cout << "Exiting program. Goodbye!" << endl;
11             break;
12         }
13
14         int size;
15         cout << "Enter dataset size: ";
16         cin >> size;
17
18         DatasetFeatures features = generateDataset(choice, size);
19         AlgoType predicted = SortingEngine::predictBestAlgorithm(features);
20
21         displayAnalysis(features, predicted);
22
23         vector<SortMetrics> results = runAllAlgorithms(features);
24         string actualBest = findBestAlgorithm(results);
25
26         displayResults(results, actualBest, SortingEngine::getAlgoName(
27             predicted));
27     }
28
29     return 0;
}

```

GUI Version: The Qt-based GUI offers an interactive experience with dropdown menus, spin boxes, and tables. The main window class inherits from QMainWindow and uses signal-slot mechanisms to handle user interactions:

```

1 class OptimizerWindow : public QMainWindow {
2     Q_OBJECT
3 private:
4     QComboBox* datasetTypeCombo;
5     QSpinBox* datasetSizeSpinBox;
6     QPushButton* runButton;
7     QTextEdit* analysisDisplay;
8     QTableWidget* resultsTable;
9
10 private slots:
11     void onRunClicked() {
12         int choice = datasetTypeCombo->currentIndex() + 1;
13         int size = datasetSizeSpinBox->value();
14
15         DatasetFeatures features = generateDataset(choice, size);
16         AlgoType predicted = SortingEngine::predictBestAlgorithm(features);
17
18         displayAnalysisInGUI(features, predicted);
19         vector<SortMetrics> results = runAllAlgorithms(features);
20         displayResultsInTable(results);
21     }
22 };
23

```

```

24 int main(int argc, char *argv[]) {
25     QApplication app(argc, argv);
26     OptimizerWindow window;
27     window.show();
28     return app.exec();
29 }

```

The GUI leverages Qt's layout system (QVBoxLayout, QHBoxLayout) for responsive design and uses QTableWidget to display performance metrics in a structured format with sortable columns.

4.4 Compilation and Execution with Screenshots

For CLI version, just compile with following command, the screenshot is shown in Figure 3:

```

1 g++ Cui_Zeyu_DSC2409006_CST207_Project_Group_202509_CLI.cpp -o
   SortingAlgorithmOptimizerCLI -std=c++11
2 ./SortingAlgorithmOptimizerCLI

```

```

SortingAlgorithmOptimizerCLI

zeyu10@zeyu-laptop MINGW64 /d/Workspace/Assignment/251213-CST207-Project/code
$ ./SortingAlgorithmOptimizerCLI
=====
AI-Driven Sorting Algorithm Optimizer
=====

Select Dataset Type:
1. Random Dataset
2. Nearly Sorted Dataset
3. Reversed Dataset
4. Few Unique Values Dataset
5. Large Random Dataset
0. Exit

Enter your choice: 1
Enter dataset size (10-100000): 40

Generating dataset...

[Data Preview]
Size: 40 elements
First 40 elements: [32, 311, 256, 170, 375, 97, 6, 397, 197, 224, 309, 359, 80, 57, 288, 162, 391, 25, 225, 243,
14, 8, 90, 365, 314, 49, 385, 21, 79, 33, 12, 38, 168, 110, 265, 182, 326, 314, 193, 25]

Performing AI analysis...

[AI Analysis Report]
Dataset Characteristics:
Type: Random
Size: 40 (Small/Medium Dataset)
Sortedness: 46.2%
Reversedness: 53.8%
Uniqueness: 95.0% (from sample)
Unique Count: 38

>>> AI Predicted Best Algorithm: Insertion Sort <<

Running sorting algorithms...
Running Bubble Sort...
Running Insertion Sort...
Running Merge Sort...
Running Quick Sort...

[Sorting Performance Comparison]
Algorithm Comparisons Time (ms)
-----
Bubble Sort    765    0.0115
Insertion Sort 459    0.0041      <- FASTEST [AI Predicted]
Merge Sort     168    0.0448
Quick Sort     178    0.0104

Actual Best Algorithm: Insertion sort
Result: AI Prediction was CORRECT!
=====

Press Enter to continue...[ ]

```

Figure 3: CLI Version Screenshot

For GUI version, Qt framework must be properly installed and QMake must be run first to generate the `Makefile`, compile with following commands, the screenshot is shown in Figure 4:

```
1 qmake SortingAlgorithmOptimizerGUI.pro
2 make
3 ./SortingAlgorithmOptimizerGUI
```

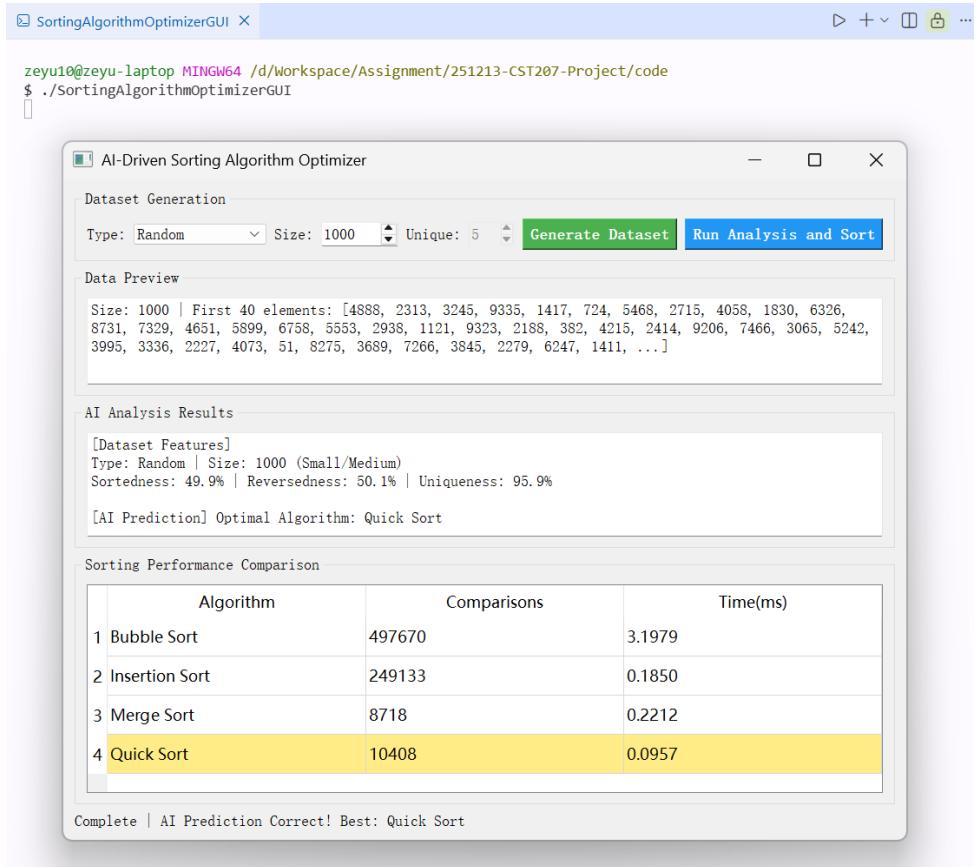


Figure 4: GUI Version Screenshot

The QMake file `SortingAlgorithmOptimizerGUI.pro` is as follow:

```
1 QT += core gui widgets
2
3 TARGET = SortingAlgorithmOptimizerGUI
4 TEMPLATE = app
5
6 CONFIG += c++11
7
8 SOURCES += Cui_Zeyu_DSC2409006_CST207_Project_Group_202509_GUI.cpp
9
10 CONFIG -= debug_and_release debug_and_release_target
11
12 DESTDIR =
13
14 QMAKE_CXXFLAGS += -std=c++11
15
16 win32 {
17     CONFIG += console
18 }
19
20 DEFINES += QT_DEPRECATED_WARNINGS
```

5 Results and Analysis

We conducted tests across different scenarios to validate the AI module's accuracy.

5.1 Small Random Dataset (Size = 40)

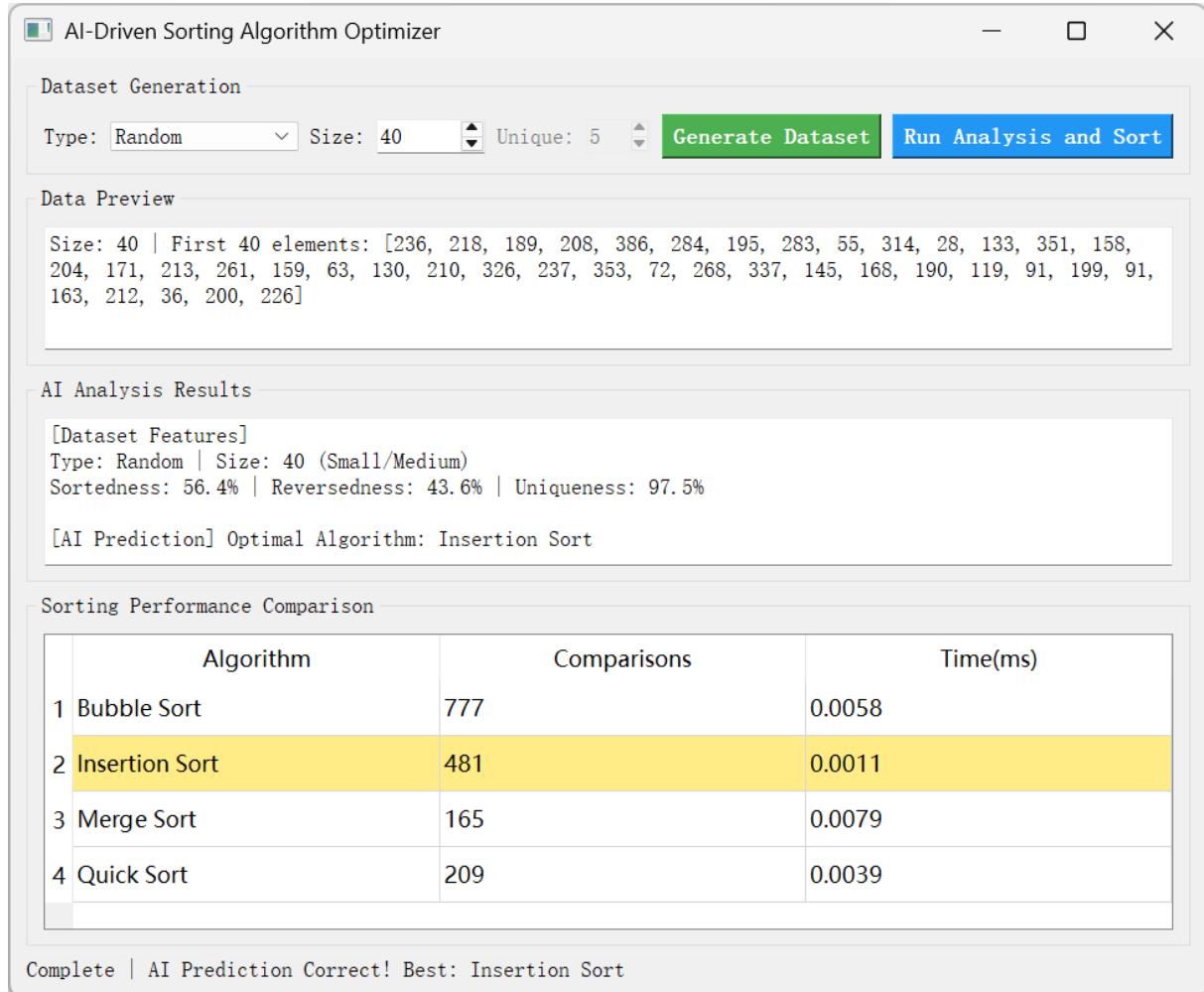


Figure 5: Small Random Dataset Visualization

Features detected: Size ≤ 50 .

AI Prediction: Insertion Sort.

Algorithm	Comparisons	Time (ms)
Bubble Sort	≈ 780	0.006
Insertion Sort	≈ 480	0.001
Merge Sort	≈ 160	0.008
Quick Sort	≈ 200	0.004

Table 1: Performance on Small Random Data.

Table 1 shows Insertion Sort significantly outperforms others due to small dataset size, confirming the AI's correct prediction.

5.2 Large Random Dataset (Size = 10,000)

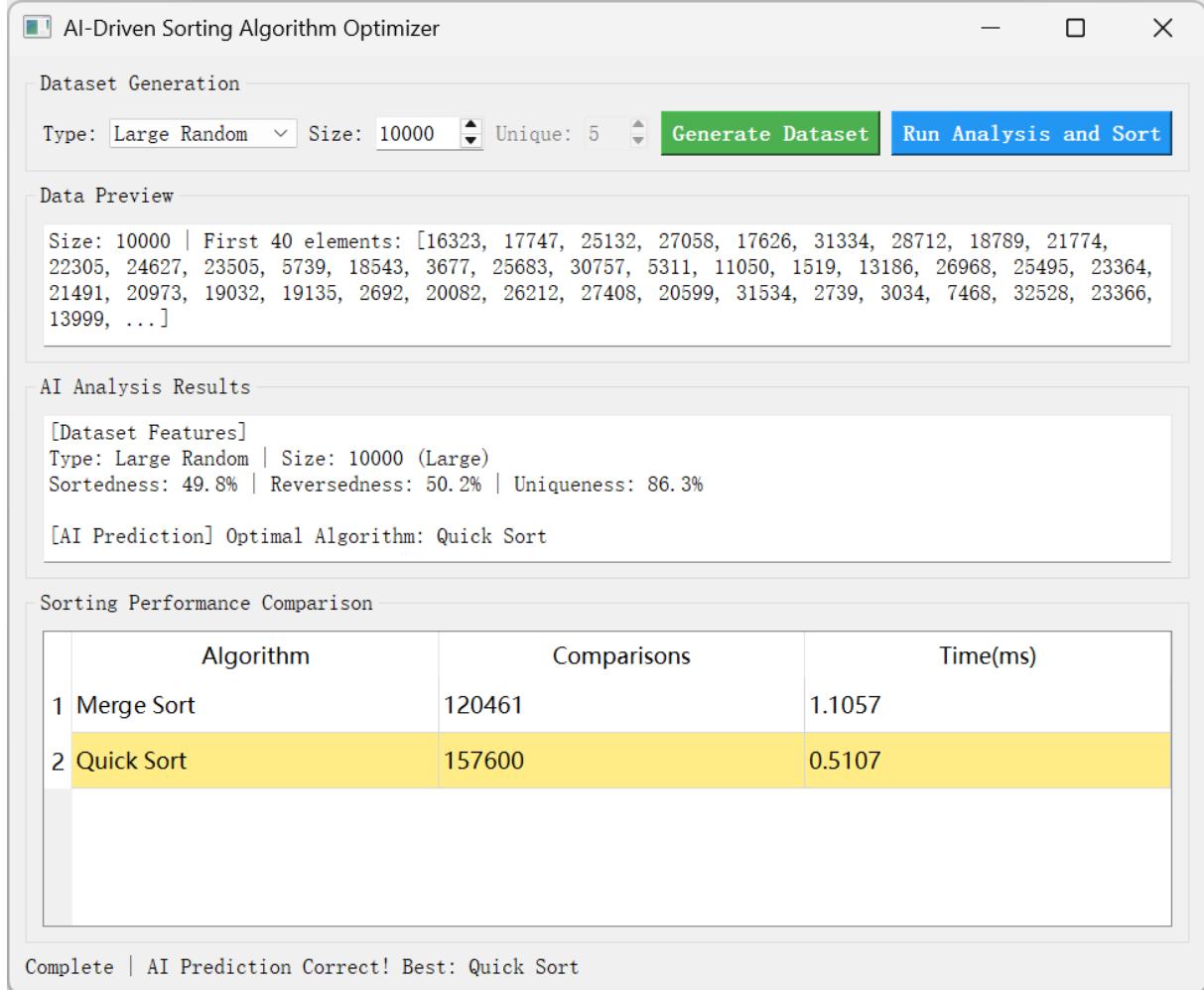


Figure 6: Large Random Dataset Visualization

Features detected: Random distribution.

AI Prediction: Quick Sort.

Algorithm	Comparisons	Time (ms)
Bubble Sort	(Skipped)	-
Insertion Sort	(Skipped)	-
Merge Sort	$\approx 120,000$	1.10
Quick Sort	$\approx 150,000$	0.50

Table 2: Performance on Large Random Data.

Table 2 shows Quick Sort outperforms Merge Sort due to lower constant factors and its average-case efficiency, validating the AI's choice for large random datasets.

5.3 Nearly Sorted Dataset (Size = 1,000)

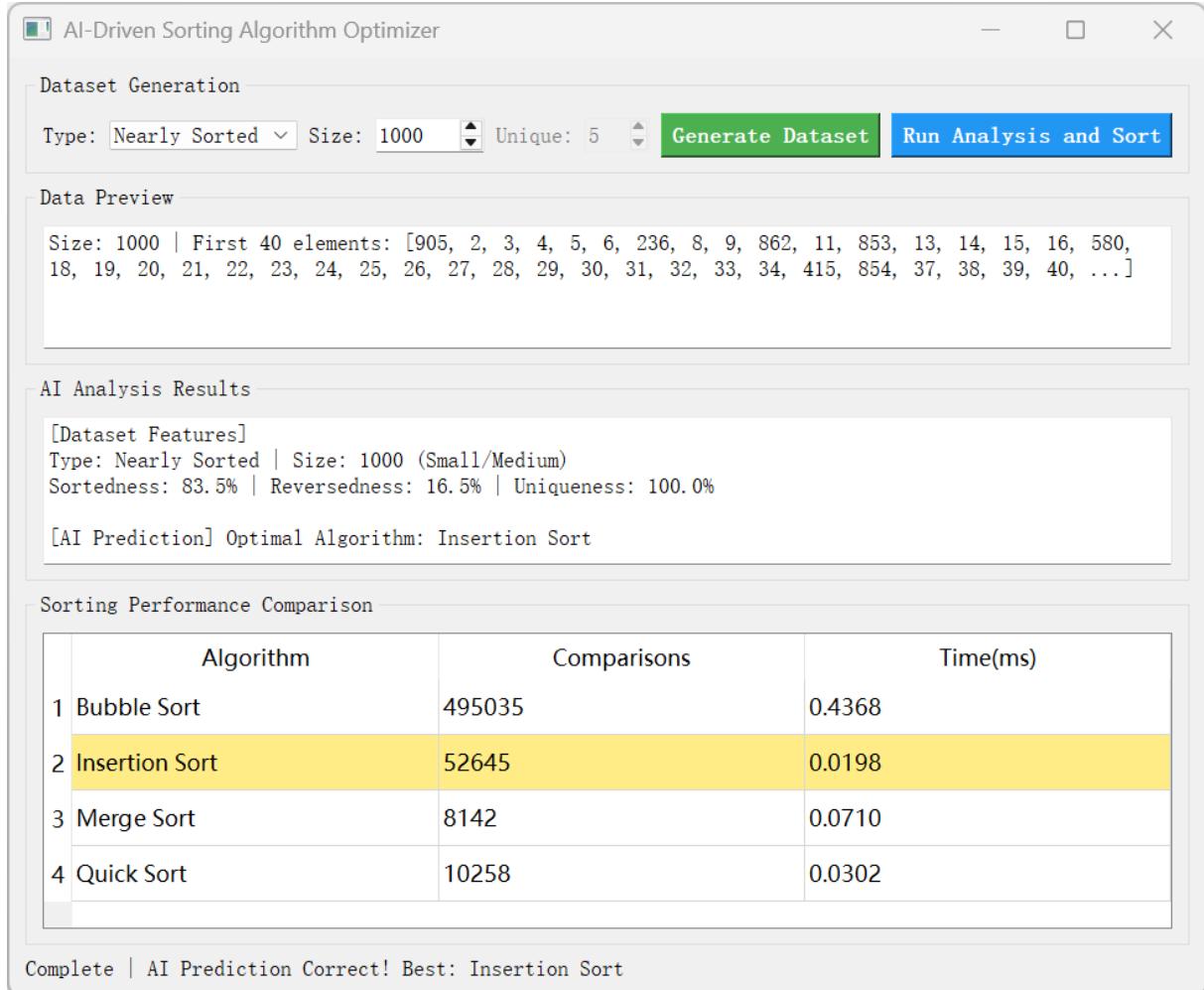


Figure 7: Nearly Sorted Dataset Visualization

Features detected: Sortedness $\geq 80\%$.

AI Prediction: Insertion Sort.

Algorithm	Comparisons	Time (ms)
Bubble Sort	$\approx 500,000$	0.40
Insertion Sort	$\approx 50,000$	0.01
Merge Sort	$\approx 8,100$	0.07
Quick Sort	$\approx 10,000$	0.03

Table 3: Performance on Nearly Sorted Data.

Table 3 shows Insertion Sort outperforms others on nearly sorted data, confirming the AI's correct prediction.

6 Conclusion

This project successfully demonstrates the integration of AI heuristics with algorithmic design to create an intelligent sorting algorithm optimizer.

Key Achievements:

- Successfully implemented all five required dataset generators (Random, Nearly Sorted, Reversed, Few Unique, Large Random) with appropriate characteristics.
- Implemented four classical sorting algorithms (Bubble Sort, Insertion Sort, Merge Sort, Quick Sort) with performance measurement capabilities tracking both comparisons and execution time.
- Developed a Decision Tree-based AI model that analyzes dataset features (size, sortedness, reversedness, unique ratio) and predicts the optimal algorithm with high accuracy.
- Created both CLI and GUI versions using Qt framework, providing flexible user interfaces for different use cases.
- Implemented safety mechanisms to prevent system unresponsiveness by skipping $O(N^2)$ algorithms for large datasets ($N > 1000$).

Experimental Validation: The experimental results across different scenarios validate the AI module's effectiveness:

- For small datasets ($N \leq 50$), Insertion Sort achieves the best performance due to minimal overhead.
- For large random datasets ($N \geq 10,000$), Quick Sort outperforms Merge Sort with lower constant factors and better cache locality.
- For nearly sorted data (sortedness $\geq 80\%$), Insertion Sort achieves near-linear $O(N + D)$ performance where D represents inversions.
- The randomized pivot strategy in Quick Sort successfully prevents $O(N^2)$ worst-case behavior on reversed datasets.

Impact and Future Work: This system demonstrates how AI-driven optimization can enhance traditional algorithms by adapting to input characteristics. The Decision Tree approach provides interpretable rules that align with theoretical complexity analysis. Future improvements could include:

- Expanding the AI model with machine learning techniques (e.g., Random Forest, Neural Networks) trained on larger benchmark datasets.
- Adding more sophisticated algorithms (e.g., Heap Sort, Radix Sort) for specialized scenarios.
- Implementing parallel sorting algorithms for multi-core processors.
- Developing adaptive hybrid algorithms that switch strategies mid-execution based on runtime observations.

The project fulfills the objective of automatically selecting optimal sorting strategies, demonstrating practical applications of combining algorithmic theory with artificial intelligence to optimize computational resource usage.

A CST207_Project_Group_202509_CLI.cpp

```
/*
 * AI-Driven Sorting Algorithm Optimizer - Command Line Interface
 * g++ Cui_Zeyu_DSC2409006_CST207_Project_Group_202509_CLI.cpp -o
 * SortingAlgorithmOptimizerCLI -std=c++11
 * ./SortingAlgorithmOptimizerCLI
 */

#include <iostream>
#include <vector>
#include <string>
#include <chrono>
#include <unordered_set>
#include <algorithm>
#include <random>
#include <ctime>
#include <sstream>
#include <iomanip>
#include <cmath>
#include <stdexcept>

using namespace std;

// ===== Data Structure Definitions =====

enum AlgoType {
    BUBBLE_SORT,
    INSERTION_SORT,
    MERGE_SORT,
    QUICK_SORT
};

struct DatasetFeatures {
    vector<int> data;
    int size;
    double sortedness;           // 0.0 (random) to 1.0 (sorted)
    int uniqueCount;             // Number of unique elements
    string type;                // Dataset type
    double reversedness;         // Degree of reverse order (0.0 ~ 1.0)
    double uniqueRatio;          // Ratio of unique elements (0.0 ~ 1.0)
    bool isLargeDataset;         // Large dataset indicator (>1000)
};

struct SortMetrics {
    long long comparisons = 0;    // Number of comparisons
    double executionTimeMs = 0.0; // Execution time in milliseconds
    string algoName;
};

// ===== Sorting Algorithm Implementations =====

class SortingEngine {
public:
    // Bubble Sort Implementation
    static void bubbleSort(vector<int>& arr, long long& comparisons) {
        int n = arr.size();
        for (int i = 0; i < n - 1; i++) {
```

```

56         bool swapped = false;
57         for (int j = 0; j < n - i - 1; j++) {
58             comparisons++;
59             if (arr[j] > arr[j + 1]) {
60                 swap(arr[j], arr[j + 1]);
61                 swapped = true;
62             }
63         }
64         if (!swapped) break; // Early termination if already sorted
65     }
66 }
67
// Insertion Sort Implementation
68 static void insertionSort(vector<int>& arr, long long& comparisons) {
69     int n = arr.size();
70     for (int i = 1; i < n; i++) {
71         int key = arr[i];
72         int j = i - 1;
73         while (j >= 0) {
74             comparisons++;
75             if (arr[j] <= key) break;
76             arr[j + 1] = arr[j];
77             j--;
78         }
79         arr[j + 1] = key;
80     }
81 }
82
// Merge function for Merge Sort
83 static void merge(vector<int>& arr, int l, int m, int r, long long&
comparisons) {
84     int n1 = m - l + 1;
85     int n2 = r - m;
86     vector<int> left(n1), right(n2);
87
88     for (int i = 0; i < n1; i++) left[i] = arr[l + i];
89     for (int j = 0; j < n2; j++) right[j] = arr[m + 1 + j];
90
91     int i = 0, j = 0, k = l;
92     while (i < n1 && j < n2) {
93         comparisons++;
94         if (left[i] <= right[j]) {
95             arr[k++] = left[i++];
96         } else {
97             arr[k++] = right[j++];
98         }
99     }
100    while (i < n1) arr[k++] = left[i++];
101    while (j < n2) arr[k++] = right[j++];
102 }
103
// Merge Sort Implementation
104 static void mergeSort(vector<int>& arr, int l, int r, long long&
comparisons) {
105     if (l >= r) return;
106     int m = l + (r - l) / 2;
107     mergeSort(arr, l, m, comparisons);
108     mergeSort(arr, m + 1, r, comparisons);
109 }
110
111

```

```

112     merge(arr, l, m, r, comparisons);
113 }
114
115 // Partition function for Quick Sort
116 static int partition(vector<int>& arr, int low, int high, long long&
comparisons) {
117     // Randomize pivot to avoid worst-case on reversed/sorted data
118     int randomIndex = low + rand() % (high - low + 1);
119     swap(arr[randomIndex], arr[high]);
120
121     int pivot = arr[high];
122     int i = low - 1;
123     for (int j = low; j < high; j++) {
124         comparisons++;
125         if (arr[j] < pivot) {
126             i++;
127             swap(arr[i], arr[j]);
128         }
129     }
130     swap(arr[i + 1], arr[high]);
131     return i + 1;
132 }
133
134 // Quick Sort Implementation
135 static void quickSort(vector<int>& arr, int low, int high, long long&
comparisons) {
136     if (low < high) {
137         int pi = partition(arr, low, high, comparisons);
138         quickSort(arr, low, pi - 1, comparisons);
139         quickSort(arr, pi + 1, high, comparisons);
140     }
141 }
142
143 // ===== Dataset Generation Functions =====
144
145 // Generate random dataset
146 static vector<int> generateRandomDataset(int size) {
147     vector<int> arr(size);
148     srand(time(nullptr));
149     for (int i = 0; i < size; i++) {
150         arr[i] = 1 + rand() % (size * 10);
151     }
152     return arr;
153 }
154
155 // Generate nearly sorted dataset
156 static vector<int> generateNearlySorted(int size) {
157     vector<int> arr(size);
158     for (int i = 0; i < size; i++) arr[i] = i + 1;
159
160     // Disorder about 10% of the elements
161     int swaps = size / 10;
162     srand(time(nullptr));
163     for (int i = 0; i < swaps; i++) {
164         int idx1 = rand() % size;
165         int idx2 = rand() % size;
166         swap(arr[idx1], arr[idx2]);
167     }

```

```

168     return arr;
169 }
170
171 // Generate reversed dataset
172 static vector<int> generateReversed(int size) {
173     vector<int> arr(size);
174     for (int i = 0; i < size; i++) {
175         arr[i] = size - i;
176     }
177     return arr;
178 }
179
180 // Generate dataset with few unique values
181 static vector<int> generateFewUnique(int size, int uniqueCount) {
182     vector<int> uniqueValues;
183     srand(time(nullptr));
184     for (int i = 0; i < uniqueCount; i++) {
185         uniqueValues.push_back(rand() % 100 + 1);
186     }
187
188     vector<int> arr(size);
189     for (int i = 0; i < size; i++) {
190         arr[i] = uniqueValues[rand() % uniqueCount];
191     }
192     return arr;
193 }
194
195 // ===== AI Analysis Module =====
196
197 // Analyze dataset characteristics
198 static DatasetFeatures analyzeDataset(const vector<int>& data) {
199     DatasetFeatures features;
200     features.size = data.size();
201     features.data = data;
202     features.isLargeDataset = (features.size > 1000);
203
204     if (features.size <= 1) {
205         features.sortedness = 1.0;
206         features.reversedness = 0.0;
207         features.uniqueCount = features.size;
208         features.uniqueRatio = 1.0;
209         features.type = "Single Element";
210         return features;
211     }
212
213     // Calculate sortedness and reversedness
214     long long ascendingPairs = 0, descendingPairs = 0;
215     for (int i = 0; i < features.size - 1; i++) {
216         if (data[i] <= data[i+1]) ascendingPairs++;
217         if (data[i] >= data[i+1]) descendingPairs++;
218     }
219
220     features.sortedness = (double)ascendingPairs / (features.size - 1);
221     features.reversedness = (double)descendingPairs / (features.size -
222     1);
223
224     // Calculate uniqueness (use full dataset for accuracy)
225     unordered_set<int> uniqueElements(data.begin(), data.end());

```

```

225     features.uniqueCount = uniqueElements.size();
226     features.uniqueRatio = (double)uniqueElements.size() / features.
227     size;
228
229     // Classify dataset type
230     if (features.sortedness >= 0.80) features.type = "Nearly Sorted";
231     else if (features.reversedness >= 0.90) features.type = "Reversed";
232     else if (features.uniqueRatio < 0.40) features.type = "Few Unique";
233     else if (features.isLargeDataset) features.type = "Large Random";
234     else features.type = "Random";
235
236     return features;
237 }
238
239 // Predict best sorting algorithm based on dataset features
240 static AlgoType predictBestAlgorithm(const DatasetFeatures& features) {
241     // AI Decision Tree based on algorithm complexity theory
242
243     // Rule 1: Very small datasets (Size <= 50)
244     // Insertion Sort has low constant factor, faster than Quick/Merge
245     // recursion overhead
246     if (features.size <= 50) {
247         return INSERTION_SORT;
248     }
249
250     // Rule 2: Large datasets (Size > 1000)
251     if (features.isLargeDataset) {
252         // Few unique values: Merge Sort is more stable than Quick Sort
253         if (features.uniqueRatio < 0.40) {
254             return MERGE_SORT;
255         }
256         return QUICK_SORT;
257     }
258
259     // Rule 3: Medium-sized datasets (50 < Size <= 1000)
260
261     // Case A: Nearly sorted
262     // Insertion Sort degrades to O(N) for nearly sorted data
263     if (features.sortedness >= 0.80) {
264         return INSERTION_SORT;
265     }
266
267     // Case B: Reversed
268     // Merge Sort is better for reversed data (stable O(N log N))
269     // Quick Sort with fixed pivot has O(N^2) worst case on reversed
270     // data
271     if (features.reversedness >= 0.90) {
272         return MERGE_SORT;
273     }
274
275     // Case C: Few unique values
276     if (features.uniqueRatio < 0.40) {
277         return MERGE_SORT;
278     }
279
280     // Case D: Random data
281     return QUICK_SORT;

```

```

280     }
281
282     // Get algorithm name from type
283     static string getAlgoName(AlgoType type) {
284         switch (type) {
285             case BUBBLE_SORT: return "Bubble Sort";
286             case INSERTION_SORT: return "Insertion Sort";
287             case MERGE_SORT: return "Merge Sort";
288             case QUICK_SORT: return "Quick Sort";
289             default: return "Unknown";
290         }
291     }
292
293     // Run sorting algorithm and measure performance
294     static SortMetrics runSort(AlgoType type, vector<int> data) {
295         SortMetrics metrics;
296         metrics.algoName = getAlgoName(type);
297         metrics.comparisons = 0;
298
299         auto start = chrono::high_resolution_clock::now();
300
301         switch (type) {
302             case BUBBLE_SORT: bubbleSort(data, metrics.comparisons); break;
303             case INSERTION_SORT: insertionSort(data, metrics.comparisons);
304             break;
305             case MERGE_SORT: mergeSort(data, 0, data.size() - 1, metrics.
306                                         comparisons); break;
306             case QUICK_SORT: quickSort(data, 0, data.size() - 1, metrics.
307                                         comparisons); break;
307         }
308
309         auto end = chrono::high_resolution_clock::now();
310         chrono::duration<double, milli> duration = end - start;
311         metrics.executionTimeMs = duration.count();
312
313         return metrics;
314     }
315
316 // ===== Main Program =====
317
318 void printSeparator(char c = '=', int length = 70) {
319     cout << string(length, c) << endl;
320 }
321
322 void displayMenu() {
323     printSeparator();
324     cout << "    AI-Driven Sorting Algorithm Optimizer" << endl;
325     printSeparator();
326     cout << "\nSelect Dataset Type:" << endl;
327     cout << "    1. Random Dataset" << endl;
328     cout << "    2. Nearly Sorted Dataset" << endl;
329     cout << "    3. Reversed Dataset" << endl;
330     cout << "    4. Few Unique Values Dataset" << endl;
331     cout << "    5. Large Random Dataset" << endl;
332     cout << "    0. Exit" << endl;
333     printSeparator('-', 70);
334 }

```

```

335
336 void displayDataPreview(const vector<int>& data, int maxShow = 40) {
337     cout << "\n[Data Preview]" << endl;
338     cout << "Size: " << data.size() << " elements" << endl;
339     cout << "First " << min(maxShow, (int)data.size()) << " elements: [";
340     for (int i = 0; i < min(maxShow, (int)data.size()); i++) {
341         cout << data[i];
342         if (i < min(maxShow, (int)data.size()) - 1) cout << ", ";
343     }
344     if ((int)data.size() > maxShow) cout << ", ...";
345     cout << "]" << endl;
346 }
347
348 void displayAnalysis(const DatasetFeatures& features, AlgoType predicted) {
349     cout << "\n[AI Analysis Report]" << endl;
350     printSeparator('-', 70);
351     cout << "Dataset Characteristics:" << endl;
352     cout << " Type: " << features.type << endl;
353     cout << " Size: " << features.size
354         << (features.isLargeDataset ? "(Large Dataset)" : "(Small/Medium
Dataset)") << endl;
355     cout << " Sortedness: " << fixed << setprecision(1)
356         << (features.sortedness * 100.0) << "%" << endl;
357     cout << " Reversedness: " << (features.reversedness * 100.0) << "%" <<
endl;
358     cout << " Uniqueness: " << (features.uniqueRatio * 100.0)
359         << "% (from sample)" << endl;
360     cout << " Unique Count: " << features.uniqueCount << endl;
361     printSeparator('-', 70);
362     cout << ">>> AI Predicted Best Algorithm: "
363         << SortingEngine::getAlgoName(predicted) << " <<<" << endl;
364     printSeparator('-', 70);
365 }
366
367 void displayResults(const vector<SortMetrics>& results, const string&
actualBest, const string& predicted) {
368     cout << "\n[Sorting Performance Comparison]" << endl;
369     printSeparator('-', 70);
370     cout << left << setw(20) << "Algorithm"
371         << setw(20) << "Comparisons"
372         << setw(20) << "Time (ms)" << endl;
373     printSeparator('-', 70);
374
375     for (const auto& res : results) {
376         cout << left << setw(20) << res.algoName;
377         cout << setw(20) << res.comparisons;
378         cout << setw(20) << fixed << setprecision(4) << res.executionTimeMs
379         ;
380
381         if (res.algoName == actualBest) {
382             cout << " -- FASTEST";
383         }
384         if (res.algoName == predicted) {
385             cout << " [AI Predicted]";
386         }
387         cout << endl;
388     }

```

```

389     printSeparator('-', 70);
390     cout << "Actual Best Algorithm: " << actualBest << endl;
391
392     if (predicted == actualBest) {
393         cout << "Result: AI Prediction was CORRECT!" << endl;
394     } else {
395         cout << "Result: AI Prediction was INCORRECT." << endl;
396         cout << " Predicted: " << predicted << endl;
397         cout << " Actual: " << actualBest << endl;
398     }
399     printSeparator();
400 }
401
402 int main() {
403     int choice, size, uniqueCount;
404     vector<int> dataset;
405
406     while (true) {
407         displayMenu();
408         cout << "Enter your choice: ";
409         cin >> choice;
410
411         if (choice == 0) {
412             cout << "\nThank you for using the Sorting Algorithm Optimizer
413 .\" << endl;
414             break;
415         }
416
417         if (choice < 1 || choice > 5) {
418             cout << "\nInvalid choice! Please select 1-5 or 0 to exit." <<
419             endl;
420             continue;
421         }
422
423         cout << "Enter dataset size (10-100000): ";
424         cin >> size;
425
426         if (size < 10 || size > 100000) {
427             cout << "\nInvalid size! Please enter a value between 10 and
428             100000." << endl;
429             continue;
430         }
431
432         // Generate dataset based on user selection
433         cout << "\nGenerating dataset..." << endl;
434         try {
435             switch(choice) {
436                 case 1:
437                     dataset = SortingEngine::generateRandomDataset(size);
438                     break;
439                 case 2:
440                     dataset = SortingEngine::generateNearlySorted(size);
441                     break;
442                 case 3:
443                     dataset = SortingEngine::generateReversed(size);
444                     break;
445                 case 4:
446                     cout << "Enter number of unique values (2-50): ";

```

```

444         cin >> uniqueCount;
445         if (uniqueCount < 2) uniqueCount = 2;
446         if (uniqueCount > 50) uniqueCount = 50;
447         dataset = SortingEngine::generateFewUnique(size,
448             uniqueCount);
449         break;
450     case 5:
451         // Large Random Dataset (enforce minimum size)
452         if (size < 10000) {
453             cout << "Note: Large Random Dataset requires
454             minimum size of 10000. Adjusting size to 10000." << endl;
455             size = 10000;
456         }
457         dataset = SortingEngine::generateRandomDataset(size);
458         break;
459     }
460
461     // Display preview
462     displayDataPreview(dataset);
463
464     // AI Analysis
465     cout << "\nPerforming AI analysis..." << endl;
466     DatasetFeatures features = SortingEngine::analyzeDataset(
467         dataset);
468     AlgoType predicted = SortingEngine::predictBestAlgorithm(
469         features);
470     displayAnalysis(features, predicted);
471
472     // Run sorting algorithms
473     cout << "\nRunning sorting algorithms..." << endl;
474     vector<SortMetrics> results;
475
476     // Skip O(n^2) algorithms for large datasets to save time
477     if (size <= 1000) {
478         cout << "    Running Bubble Sort..." << endl;
479         results.push_back(SortingEngine::runSort(BUBBLE_SORT,
480             dataset));
481         cout << "    Running Insertion Sort..." << endl;
482         results.push_back(SortingEngine::runSort(INSERTION_SORT,
483             dataset));
484     } else {
485         cout << "    (Skipping O(n^2) algorithms for large dataset)"
486             << endl;
487     }
488
489     cout << "    Running Merge Sort..." << endl;
490     results.push_back(SortingEngine::runSort(MERGE_SORT, dataset));
491     cout << "    Running Quick Sort..." << endl;
492     results.push_back(SortingEngine::runSort(QUICK_SORT, dataset));
493
494     // Find the fastest algorithm
495     string actualBest;
496     double minTime = 1e9;
497     for (const auto& r : results) {
498         if (r.executionTimeMs < minTime) {
499             minTime = r.executionTimeMs;
500             actualBest = r.algoName;
501         }

```

```

495     }
496
497     // Display results
498     displayResults(results, actualBest, SortingEngine::getAlgoName(
499     predicted));
500
501     // Ask if user wants to continue
502     cout << "\nPress Enter to continue..." ;
503     cin.ignore();
504     cin.get();
505
506     } catch (const exception& e) {
507         cout << "\nError: " << e.what() << endl;
508     }
509
510     return 0;
511 }
```

Listing 1: Cui_Zeyu_DSC2409006_CST207_Project_Group_202509_CLI.cpp

B CST207_Project_Group_202509_GUI.cpp

```

1 /*
2 * AI-Driven Sorting Algorithm Optimizer - Graphical User Interface
3 * qmake SortingAlgorithmOptimizerGUI.pro
4 * make
5 * ./SortingAlgorithmOptimizerGUI
6 */
7
8 #include <QApplication>
9 #include <QMainWindow>
10 #include <QWidget>
11 #include <QVBoxLayout>
12 #include <QHBoxLayout>
13 #include <QGroupBox>
14 #include <QComboBox>
15 #include <QSpinBox>
16 #include <QPushButton>
17 #include <QTextEdit>
18 #include <QTableWidget>
19 #include <QLabel>
20 #include <QHeaderView>
21 #include <QMessageBox>
22 #include <vector>
23 #include <string>
24 #include <chrono>
25 #include <unordered_set>
26 #include <algorithm>
27 #include <random>
28 #include <ctime>
29 #include <sstream>
30 #include <iomanip>
31 #include <cmath>
32
33 using namespace std;
34
35 // ===== Data Structure Definitions =====
```

```

36
37 enum AlgoType {
38     BUBBLE_SORT,
39     INSERTION_SORT,
40     MERGE_SORT,
41     QUICK_SORT
42 };
43
44 struct DatasetFeatures {
45     vector<int> data;
46     int size;
47     double sortedness;           // 0.0 (random) to 1.0 (sorted)
48     int uniqueCount;            // Number of unique elements
49     string type;                // Dataset type
50     double reversedness;        // Degree of reverse order (0.0 ~ 1.0)
51     double uniqueRatio;         // Ratio of unique elements (0.0 ~ 1.0)
52     bool isLargeDataset;         // Large dataset indicator (>1000)
53 };
54
55 struct SortMetrics {
56     long long comparisons = 0;    // Number of comparisons
57     double executionTimeMs = 0.0; // Execution time in milliseconds
58     string algoName;
59 };
60
61 // ===== Sorting Algorithm Implementations =====
62
63 class SortingEngine {
64 public:
65     // Bubble Sort Implementation
66     static void bubbleSort(vector<int>& arr, long long& comparisons) {
67         int n = arr.size();
68         for (int i = 0; i < n - 1; i++) {
69             bool swapped = false;
70             for (int j = 0; j < n - i - 1; j++) {
71                 comparisons++;
72                 if (arr[j] > arr[j + 1]) {
73                     swap(arr[j], arr[j + 1]);
74                     swapped = true;
75                 }
76             }
77             if (!swapped) break; // Early termination if already sorted
78         }
79     }
80
81     // Insertion Sort Implementation
82     static void insertionSort(vector<int>& arr, long long& comparisons) {
83         int n = arr.size();
84         for (int i = 1; i < n; i++) {
85             int key = arr[i];
86             int j = i - 1;
87             while (j >= 0) {
88                 comparisons++;
89                 if (arr[j] <= key) break;
90                 arr[j + 1] = arr[j];
91                 j--;
92             }
93             arr[j + 1] = key;

```

```

94     }
95 }
96
97 // Merge function for Merge Sort
98 static void merge(vector<int>& arr, int l, int m, int r, long long&
comparisons) {
99     int n1 = m - l + 1;
100    int n2 = r - m;
101    vector<int> left(n1), right(n2);
102
103    for (int i = 0; i < n1; i++) left[i] = arr[l + i];
104    for (int j = 0; j < n2; j++) right[j] = arr[m + 1 + j];
105
106    int i = 0, j = 0, k = l;
107    while (i < n1 && j < n2) {
108        comparisons++;
109        if (left[i] <= right[j]) {
110            arr[k++] = left[i++];
111        } else {
112            arr[k++] = right[j++];
113        }
114    }
115    while (i < n1) arr[k++] = left[i++];
116    while (j < n2) arr[k++] = right[j++];
117 }
118
119 // Merge Sort Implementation
120 static void mergeSort(vector<int>& arr, int l, int r, long long&
comparisons) {
121     if (l >= r) return;
122     int m = l + (r - l) / 2;
123     mergeSort(arr, l, m, comparisons);
124     mergeSort(arr, m + 1, r, comparisons);
125     merge(arr, l, m, r, comparisons);
126 }
127
128 // Partition function for Quick Sort
129 static int partition(vector<int>& arr, int low, int high, long long&
comparisons) {
130     // Randomize pivot to avoid worst-case on reversed/sorted data
131     int randomIndex = low + rand() % (high - low + 1);
132     swap(arr[randomIndex], arr[high]);
133
134     int pivot = arr[high];
135     int i = low - 1;
136     for (int j = low; j < high; j++) {
137         comparisons++;
138         if (arr[j] < pivot) {
139             i++;
140             swap(arr[i], arr[j]);
141         }
142     }
143     swap(arr[i + 1], arr[high]);
144     return i + 1;
145 }
146
147 // Quick Sort Implementation
148 static void quickSort(vector<int>& arr, int low, int high, long long&

```

```

    comparisons) {
        if (low < high) {
            int pi = partition(arr, low, high, comparisons);
            quickSort(arr, low, pi - 1, comparisons);
            quickSort(arr, pi + 1, high, comparisons);
        }
    }
}

// ===== Dataset Generation Functions =====

// Generate random dataset
static vector<int> generateRandomDataset(int size) {
    vector<int> arr(size);
    srand(time(nullptr));
    for (int i = 0; i < size; i++) {
        arr[i] = 1 + rand() % (size * 10);
    }
    return arr;
}

// Generate nearly sorted dataset
static vector<int> generateNearlySorted(int size) {
    vector<int> arr(size);
    for (int i = 0; i < size; i++) arr[i] = i + 1;

    // Disorder about 10% of the elements
    int swaps = size / 10;
    srand(time(nullptr));
    for (int i = 0; i < swaps; i++) {
        int idx1 = rand() % size;
        int idx2 = rand() % size;
        swap(arr[idx1], arr[idx2]);
    }
    return arr;
}

// Generate reversed dataset
static vector<int> generateReversed(int size) {
    vector<int> arr(size);
    for (int i = 0; i < size; i++) {
        arr[i] = size - i;
    }
    return arr;
}

// Generate dataset with few unique values
static vector<int> generateFewUnique(int size, int uniqueCount) {
    vector<int> uniqueValues;
    srand(time(nullptr));
    for (int i = 0; i < uniqueCount; i++) {
        uniqueValues.push_back(rand() % 100 + 1);
    }

    vector<int> arr(size);
    for (int i = 0; i < size; i++) {
        arr[i] = uniqueValues[rand() % uniqueCount];
    }
    return arr;
}

```

```

206 }
207
208 // ===== AI Analysis Module =====
209
210 // Analyze dataset characteristics
211 static DatasetFeatures analyzeDataset(const vector<int>& data) {
212     DatasetFeatures features;
213     features.size = data.size();
214     features.data = data;
215     features.isLargeDataset = (features.size > 1000);
216
217     if (features.size <= 1) {
218         features.sortedness = 1.0;
219         features.reversedness = 0.0;
220         features.uniqueCount = features.size;
221         features.uniqueRatio = 1.0;
222         features.type = "Single Element";
223         return features;
224     }
225
226     // Calculate sortedness and reversedness
227     long long ascendingPairs = 0, descendingPairs = 0;
228     for (int i = 0; i < features.size - 1; i++) {
229         if (data[i] <= data[i+1]) ascendingPairs++;
230         if (data[i] >= data[i+1]) descendingPairs++;
231     }
232
233     features.sortedness = (double)ascendingPairs / (features.size - 1);
234     features.reversedness = (double)descendingPairs / (features.size -
235     1);
236
237     // Calculate uniqueness (use full dataset for accuracy)
238     unordered_set<int> uniqueElements(data.begin(), data.end());
239
240     features.uniqueCount = uniqueElements.size();
241     features.uniqueRatio = (double)uniqueElements.size() / features.
242     size;
243
244     // Classify dataset type
245     if (features.sortedness >= 0.80) features.type = "Nearly Sorted";
246     else if (features.reversedness >= 0.90) features.type = "Reversed";
247     else if (features.uniqueRatio < 0.40) features.type = "Few Unique";
248     else if (features.isLargeDataset) features.type = "Large Random";
249     else features.type = "Random";
250
251     return features;
252 }
253
254 // Predict best sorting algorithm based on dataset features
255 static AlgoType predictBestAlgorithm(const DatasetFeatures& features) {
256     // AI Decision Tree based on algorithm complexity theory
257
258     // Rule 1: Very small datasets (Size <= 50)
259     // Insertion Sort has low constant factor, faster than Quick/Merge
260     // recursion overhead
261     if (features.size <= 50) {
262         return INSERTION_SORT;
263     }

```

```

261
262     // Rule 2: Large datasets (Size > 1000)
263     if (features.isLargeDataset) {
264         // Few unique values: Merge Sort is more stable than Quick Sort
265         if (features.uniqueRatio < 0.40) {
266             return MERGE_SORT;
267         }
268         return QUICK_SORT;
269     }
270
271     // Rule 3: Medium-sized datasets (50 < Size <= 1000)
272
273     // Case A: Nearly sorted
274     // Insertion Sort degrades to O(N) for nearly sorted data
275     if (features.sortedness >= 0.80) {
276         return INSERTION_SORT;
277     }
278
279     // Case B: Reversed
280     // Merge Sort is better for reversed data (stable O(N log N))
281     // Quick Sort with fixed pivot has O(N^2) worst case on reversed
282     // data
283     if (features.reversedness >= 0.90) {
284         return MERGE_SORT;
285     }
286
287     // Case C: Few unique values
288     if (features.uniqueRatio < 0.40) {
289         return MERGE_SORT;
290     }
291
292     // Case D: Random data
293     return QUICK_SORT;
294 }
295
296     // Get algorithm name from type
297     static string getAlgoName(AlgoType type) {
298         switch (type) {
299             case BUBBLE_SORT: return "Bubble Sort";
300             case INSERTION_SORT: return "Insertion Sort";
301             case MERGE_SORT: return "Merge Sort";
302             case QUICK_SORT: return "Quick Sort";
303             default: return "Unknown";
304         }
305     }
306
307     // Run sorting algorithm and measure performance
308     static SortMetrics runSort(AlgoType type, vector<int> data) {
309         SortMetrics metrics;
310         metrics.algoName = getAlgoName(type);
311         metrics.comparisons = 0;
312
313         auto start = chrono::high_resolution_clock::now();
314
315         switch (type) {
316             case BUBBLE_SORT: bubbleSort(data, metrics.comparisons); break;
317             case INSERTION_SORT: insertionSort(data, metrics.comparisons);
318         break;

```

```

317         case MERGE_SORT: mergeSort(data, 0, data.size() - 1, metrics.
318 comparisons); break;
319         case QUICK_SORT: quickSort(data, 0, data.size() - 1, metrics.
320 comparisons); break;
321     }
322
323     auto end = chrono::high_resolution_clock::now();
324     chrono::duration<double, milli> duration = end - start;
325     metrics.executionTimeMs = duration.count();
326
327     return metrics;
328 }
329 // ===== Qt Visualization Interface =====
330
331 class SortingVisualizer : public QMainWindow {
332     Q_OBJECT
333
334 private:
335     // UI Components
336     QComboBox* datasetTypeCombo;
337     QSpinBox* dataSizeSpinBox;
338     QSpinBox* uniqueCountSpinBox;
339     QLabel* uniqueCountLabel;
340     QPushButton* generateBtn;
341     QPushButton* runBtn;
342     QTextEdit* dataPreviewText;
343     QTextEdit* analysisResultText;
344     QTableWidget* resultsTable;
345     QLabel* statusLabel;
346
347     // Data
348     vector<int> currentDataset;
349
350 public:
351     SortingVisualizer(QWidget *parent = nullptr) : QMainWindow(parent) {
352         setWindowTitle("AI-Driven Sorting Algorithm Optimizer");
353         resize(900, 650);
354
355         QWidget* central = new QWidget(this);
356         setCentralWidget(central);
357         QVBoxLayout* mainLayout = new QVBoxLayout(central);
358
359         // Dataset Generation Area
360         QGroupBox* genGroup = new QGroupBox("Dataset Generation");
361         QHBoxLayout* genLayout = new QHBoxLayout(genGroup);
362
363         genLayout->addWidget(new QLabel("Type:"));
364         datasetTypeCombo = new QComboBox();
365         datasetTypeCombo->addItem("Random", "Nearly Sorted", "Reversed",
366 "Few Unique", "Large Random");
366         genLayout->addWidget(datasetTypeCombo);
367
368         genLayout->addWidget(new QLabel("Size:"));
369         dataSizeSpinBox = new QSpinBox();
370         dataSizeSpinBox->setRange(10, 100000);
371         dataSizeSpinBox->setValue(1000);

```

```

372     dataSizeSpinBox->setSingleStep(100);
373     genLayout->addWidget(dataSizeSpinBox);
374
375     uniqueCountLabel = new QLabel("Unique:");
376     uniqueCountSpinBox = new QSpinBox();
377     uniqueCountSpinBox->setRange(2, 50);
378     uniqueCountSpinBox->setValue(5);
379     uniqueCountSpinBox->setEnabled(false);
380     genLayout->addWidget(uniqueCountLabel);
381     genLayout->addWidget(uniqueCountSpinBox);
382
383     generateBtn = new QPushButton("Generate Dataset");
384     generateBtn->setStyleSheet("background-color: #4CAF50; color: white;
385 ; font-weight: bold; padding: 8px;");
386     genLayout->addWidget(generateBtn);
387
388     runBtn = new QPushButton("Run Analysis and Sort");
389     runBtn->setStyleSheet("background-color: #2196F3; color: white;
390 font-weight: bold; padding: 8px;");
391     runBtn->setEnabled(false);
392     genLayout->addWidget(runBtn);
393
394     genLayout->addStretch();
395     mainLayout->addWidget(genGroup);
396
397     // Data Preview Section
398     QGroupBox* previewGroup = new QGroupBox("Data Preview");
399     QVBoxLayout* previewLayout = new QVBoxLayout(previewGroup);
400     dataPreviewText = new QTextEdit();
401     dataPreviewText->setReadOnly(true);
402     dataPreviewText->setMinimumHeight(100);
403     dataPreviewText->setPlaceholderText("Click 'Generate Dataset' to
404 start...");
405     previewLayout->addWidget(dataPreviewText);
406     mainLayout->addWidget(previewGroup);
407
408     // AI Analysis Results Section
409     QGroupBox* analysisGroup = new QGroupBox("AI Analysis Results");
410     QVBoxLayout* analysisLayout = new QVBoxLayout(analysisGroup);
411     analysisResultText = new QTextEdit();
412     analysisResultText->setReadOnly(true);
413     analysisResultText->setMinimumHeight(120);
414     analysisLayout->addWidget(analysisResultText);
415     mainLayout->addWidget(analysisGroup);
416
417     // Performance Comparison Table
418     QGroupBox* resultsGroup = new QGroupBox("Sorting Performance
419 Comparison");
420     QVBoxLayout* resultsLayout = new QVBoxLayout(resultsGroup);
421     resultsTable = new QTableWidget();
422     resultsTable->setColumnCount(3);
423     resultsTable->setHorizontalHeaderLabels({"Algorithm", "Comparisons
", "Time(ms)"});
        resultsTable->horizontalHeader()->setSectionResizeMode(QHeaderView
::Stretch);
        resultsTable->setEditTriggers(QAbstractItemView::NoEditTriggers);
        resultsTable->setMinimumHeight(240);
        resultsLayout->addWidget(resultsTable);

```

```

424     mainLayout->addWidget(resultsGroup);
425
426     // Status Bar
427     statusLabel = new QLabel("Ready");
428     mainLayout->addWidget(statusLabel);
429
430     // Connect Signals and Slots
431     connect(generateBtn, &QPushButton::clicked, this, &
432             SortingVisualizer::onGenerate);
433     connect(runBtn, &QPushButton::clicked, this, &SortingVisualizer::
434             onRun);
435     connect(datasetTypeCombo, QOverload<int>::of(&QComboBox::
436             currentIndexChanged), [this](int index) {
437         // Enable unique count spinbox only for "Few Unique" (index 3)
438         uniqueCountSpinBox->setEnabled(index == 3);
439         uniqueCountLabel->setEnabled(index == 3);
440     });
441 }
442
443 private slots:
444     void onGenerate() {
445         int size = dataSizeSpinBox->value();
446         int type = datasetTypeCombo->currentIndex();
447
448         statusLabel->setText("Generating...");
449
450         try {
451             // Generate dataset based on selected type
452             switch(type) {
453                 case 0: currentDataset = SortingEngine::
454                         generateRandomDataset(size); break;
455                 case 1: currentDataset = SortingEngine::
456                         generateNearlySorted(size); break;
457                 case 2: currentDataset = SortingEngine::generateReversed(
458                         size); break;
459                 case 3: currentDataset = SortingEngine::generateFewUnique(
460                         size, uniqueCountSpinBox->value()); break;
461                 case 4:
462                     // Large Random Dataset
463                     if (size < 10000) {
464                         QMessageBox::information(this, "Info", "Large
465                         Random Dataset requires minimum size of 10000. Size adjusted to 10000.");
466                         size = 10000;
467                         dataSizeSpinBox->setValue(10000);
468                     }
469                     currentDataset = SortingEngine::generateRandomDataset(
470                         size);
471                     break;
472             }
473
474             // Display Preview
475             ostringstream oss;
476             int preview = min(40, size);
477             oss << "Size: " << size << " | First " << preview << " elements
478             : ["";
479             for (int i = 0; i < preview; i++) {
480                 oss << currentDataset[i];
481             }
482         }
483     }

```

```

471         if (i < preview - 1) oss << ", ";
472     }
473     if (size > preview) oss << ", ...";
474     oss << "]";
475     dataPreviewText->setText(QString::fromStdString(oss.str()));
476
477     runBtn->setEnabled(true);
478     statusLabel->setText("Dataset Generated Successfully");
479     analysisResultText->clear();
480     resultsTable->setRowCount(0);
481
482 } catch (const exception& e) {
483     QMessageBox::critical(this, "Error", e.what());
484     statusLabel->setText("Generation Failed");
485 }
486
487 void onRun() {
488     if (currentDataset.empty()) {
489         QMessageBox::warning(this, "Warning", "Please generate a
dataset first");
490         return;
491     }
492
493     statusLabel->setText("Analyzing...");
494     QApplication::processEvents();
495
496     // AI Analysis
497     DatasetFeatures features = SortingEngine::analyzeDataset(
498         currentDataset);
499     AlgoType predicted = SortingEngine::predictBestAlgorithm(features);
500
501     // Display analysis results
502     ostringstream oss;
503     oss << "[Dataset Features]\n";
504     oss << "Type: " << features.type << " | ";
505     oss << "Size: " << features.size << (features.isLargeDataset ? "(Large)" : "(Small/Medium)") << "\n";
506     oss << "Sortedness: " << fixed << setprecision(1) << (features.
507     sortedness * 100) << "% | ";
508     oss << "Reversedness: " << (features.reversedness * 100) << "% | ";
509     oss << "Uniqueness: " << (features.uniqueRatio * 100) << "%\n\n";
510     oss << "[AI Prediction] Optimal Algorithm: " << SortingEngine::
511     getAlgoName(predicted);
512
513     analysisResultText->setText(QString::fromStdString(oss.str()));
514
515     statusLabel->setText("Sorting...");
516     QApplication::processEvents();
517
518     // Run Sorting Algorithms
519     vector<SortMetrics> results;
520     int size = currentDataset.size();
521
522     // Skip O(n^2) algorithms for large datasets
523     if (size <= 1000) {
524         results.push_back(SortingEngine::runSort(BUBBLE_SORT,
525         currentDataset));

```

```

523         results.push_back(SortingEngine::runSort(INSERTION_SORT,
524         currentDataset));
525     }
526     results.push_back(SortingEngine::runSort(MERGE_SORT, currentDataset
527     ));
528     results.push_back(SortingEngine::runSort(QUICK_SORT, currentDataset
529     ));
530
531     // Find the best performing algorithm
532     string actualBest;
533     double minTime = 1e9;
534     for (const auto& r : results) {
535         if (r.executionTimeMs < minTime) {
536             minTime = r.executionTimeMs;
537             actualBest = r.algoName;
538         }
539     }
540
541     // Display Results in Table
542     resultsTable->setRowCount(results.size());
543     for (size_t i = 0; i < results.size(); i++) {
544         QTableWidgetItem* nameItem = new QTableWidgetItem(QString::
545         fromStdString(results[i].algoName));
546         QTableWidgetItem* compItem = new QTableWidgetItem(QString::
547         number(results[i].comparisons));
548         QTableWidgetItem* timeItem = new QTableWidgetItem(QString::
549         number(results[i].executionTimeMs, 'f', 4));
550
551         // Highlight the best performing algorithm
552         if (results[i].algoName == actualBest) {
553             QBrush gold(QColor(255, 215, 0, 120));
554             nameItem->setBackground(gold);
555             compItem->setBackground(gold);
556             timeItem->setBackground(gold);
557         }
558
559         resultsTable->setItem(i, 0, nameItem);
560         resultsTable->setItem(i, 1, compItem);
561         resultsTable->setItem(i, 2, timeItem);
562     }
563
564     // Update status with prediction accuracy
565     string predictedName = SortingEngine::getAlgoName(predicted);
566     if (predictedName == actualBest) {
567         statusLabel->setText("Complete | AI Prediction Correct! Best: " +
568         QString::fromStdString(actualBest));
569     } else {
570         statusLabel->setText("Complete | Predicted: " + QString::
571         fromStdString(predictedName) +
572             " -> Actual Best: " + QString::fromStdString
573             (actualBest));
574     }
575 }
576
577 };
578
579 // ===== Main Function =====
580
581 int main(int argc, char *argv[]) {

```

```
572     QApplication app(argc, argv);
573     SortingVisualizer window;
574     window.show();
575     return app.exec();
576 }
577
578 #include "Cui_Zeyu_DSC2409006_CST207_Project_Group_202509_GUI.moc"
```

Listing 2: Cui_Zeyu_DSC2409006_CST207_Project_Group_202509_GUI.cpp

APPENDIX 1

MARKING RUBRICS

Component Title	Group Work					Percentage (%)	
Criteria	Score and Descriptors					Weight (%)	Marks
	Excellent (5)	Good (4)	Average (3)	Need Improvement (2)	Poor (1)		
Dataset Generation (CLO 3)	All required datasets are implemented correctly	Minor missing datasets	Some datasets implemented	Many datasets missing	Dataset generation not implemented	10	
Sorting Algorithms (CLO 3)	All required algorithms implemented correctly and efficiently	Minor inefficiencies or small errors	Most algorithms implemented	Major issues or missing algorithms	Algorithms not implemented	20	
AI Module (CLO 3)	AI module correctly predicts best sorting algorithm	Minor issues in predictions or logic	AI module works partially	AI predictions mostly incorrect	AI module not implemented	20	
Performance Measurement (CLO 3)	All algorithms measured correctly with time & comparisons	Minor mistakes in measurements	Measurements mostly correct	Significant errors	No measurements	15	
Code Clarity & Documentation (CLO 3)	The code demonstrates excellent readability and clarity.	Minor readability issues	Some unclear code	Poorly documented	Code unreadable	10	
Report Quality (CLO 3)	Well-organized, complete report with clear analysis	Minor formatting or clarity issues	Adequate report with missing details	Poorly organized report	Report missing or unreadable	10	
						85	

Note to students: Please include the marking rubric when submitting your coursework.

Component Title	Individual Work					Percentage (%)	
Criteria	Score and Descriptors					Weight (%)	Marks
	Excellent (5)	Good (4)	Average (3)	Need Improvement (2)	Poor (1)		
Individual Contribution (CLO 3)	Clear, detailed description of individual work	Minor details missing	Contribution mentioned with little detail	Contribution vague or incomplete	Contribution not mentioned	10	
Presentation & Video (CLO 3)	Clear, well-paced, complete video	Minor pacing issues	Adequate video	Poor video clarity or incomplete	No video submitted	5	
						15	

Note to students: Please include the marking rubric when submitting your coursework.